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U.S. DEPARTMENT OF THE NAVY
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Navy High-Pressure Waterjet Closed-Loop Paint Stripping System

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ABSTRACT

The marine refurbishment industry currently utilizes abrasive blasting for hull coatings removal. These processes generate extreme amounts of waste material, which must be contained and disposed of properly. The cost of containment the hazardous work environment and the amounts of hazardous waste produced are all significant disadvantages of the existing processes. Additionally, environmental regulations and safety standards are being introduced which demand new techniques for marine coatings removal.

In light of these factors, the U.S. Navy's Naval Surface Warfare Center - Carderock Division entered into a joint initiative with the U.S. Air Force to introduce an alternate paint and marine growth removal method, including complete effluent recovery at the source. This system, using only high pressure water, is semi-automatic and mobile. The system can operate independently in a dry-dock without external utilities. In the end, the system will eliminate the current problems associated with coatings removal and reduce the overall operational costs.

The contract for this work was awarded to Pratt & Whitney Waterjet Systems in June 1993. The work discussed is funded by the Navy under Air Force Contract F33615-91-C-5708.

BACKGROUND

In today's demanding and competitive marine refurbishment industry, new technologies are needed to replace existing blasting methods (Figure 1).

These methods are either too costly to continue or being totally banned or restricted by environmental regulations such as the Federal Water Pollution Control Act and the Water Quality Act of 1987, the Clean Air Act and the Clean Air Act Amendments.

Marine refurbishment, however, presents complex technical challenges and environmental issues because of the unique work environment.

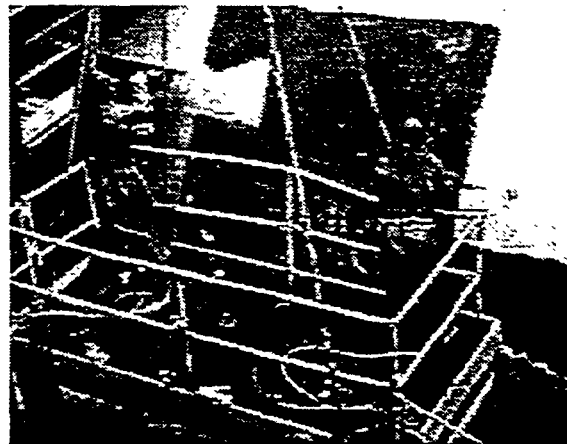


Figure 1 Typical Shipyard Hull Blasting

Environmental issues are working against the continued use of current grit and sand blasting technologies. These issues are primarily related to release into the air or water and disposal of the heavy metals used in marine coatings: copper, cadmium and lead.

The technical challenges are formidable in scale (encompassing both shipyard and drydock operations) and in effluent containment (where virtually 100% containment is the only acceptable standard). To this end, the USAF and USN have combined to produce a Waterjet Demonstration System for use in Naval and commercial shipyards.

The goal of this project is to integrate lab-demonstrated, custom-designed and off-the-shelf hardware into a prototype system to demonstrate complete removal and recovery of marine coatings. The project has been through design, fabrication, verification testing and demonstration phases, removing paints from active Navy ships. The prototype demonstration system is now being slated for production work on active Navy vessels. The system was designed as a dual-use system to provide as much benefit to the commercial shipbuilding industry as it will to the Navy.

SYSTEM DESCRIPTION

The system (Figure 2) is totally mobile and self contained for drydock, shipyard or harbor operation. Basic system elements include a high-pressure water pump, a teleoperated transporter with a 5-axis telescoping arm, a 6-axis manipulator with specialized end effector, a recovery process trailer, and a system remote control console.

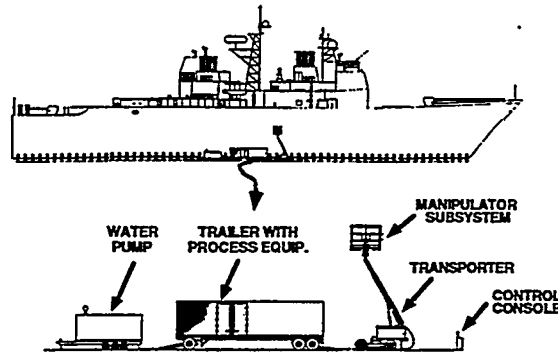


Figure 2 Coating Removal & Recovery System

The end effector incorporates a 6-inch-wide waterjet nozzle in a frame designed for precise application of the waterjet energy against the side of a ship. Stripping paths are mechanically guided by the frame. The end effector has the ability to "comply" with the various surface contour variations typically encountered on ship hulls. It also incorporates an effluent-containment shroud around the waterjet nozzle and a strong vacuum to completely contain all process water and coating residue and transfer them to the water reclamation unit.

For completely closed-loop operation, the system includes a modular water reclamation subsystem for water filtration and recirculation; the only waste product in waterjet processing is the removed coating and fouling. Finally, the entire system is completely mobile; it is transported on wheeled trailers.

System Advantages

The waterjet process is inherently superior to conventional marine coating removal methods, such as grit blasting, shot peening, sanding, chipping, scraping or brushing; it offers the major advantages listed below:

- Paint is the only waste product,
- No dust or airborne contaminants,
- Requires no containment structures,
- Does not subject workers or the environment to hazardous waste,
- Very effective removal of surface contaminants such as salts, "

Ability to selectively strip layers of a coating or entire coating in one pass,
Eliminates the need for respirators or masking of mechanical equipment
Other operations can be performed in unison.
Leaves surface clean and dry,
Requires no cleanup after stripping,
Lower manpower requirements and higher paint-removal rates,
Allows repainting with no additional surface preparation, and
Meets environmental concerns and has potential for large cost savings.

Subsystem Specifications

The Navy Waterjet Demonstration System (Figure 3) consists of an end-effector subsystem (nozzle, effluent-recovery shroud, nozzle rotation drive, and controls), a high-pressure pump, an effluent-recovery and water reclamation system, a manipulator and transporter, all on compact mobile trailers for maneuverability in shipyard areas.

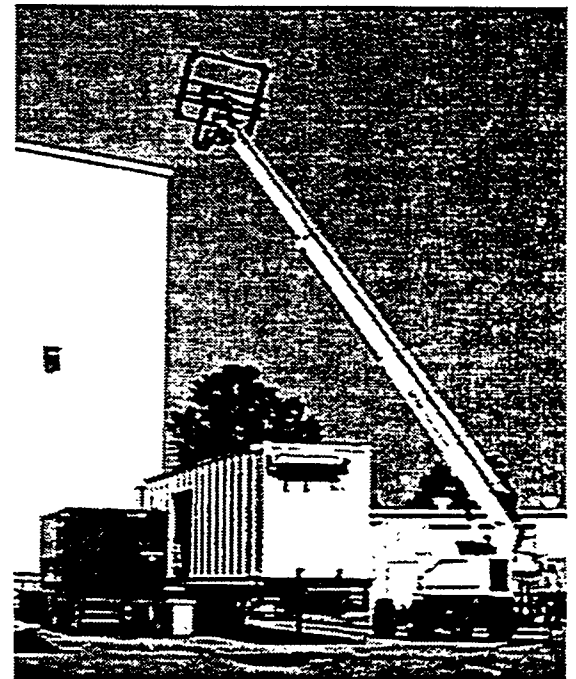


Figure 3 Mobile, Self-Contained System (11 Axes)

End Effector Subsystem

The end effector subsystem (Figure 4) is a self-contained nozzle and shroud assembly with a hydraulically controlled, 15-cm (6-inch) wide stripping nozzle. Controls are included for nozzle standoff distance and compliance (mating to the

coated surface contour) for complete effluent capture.

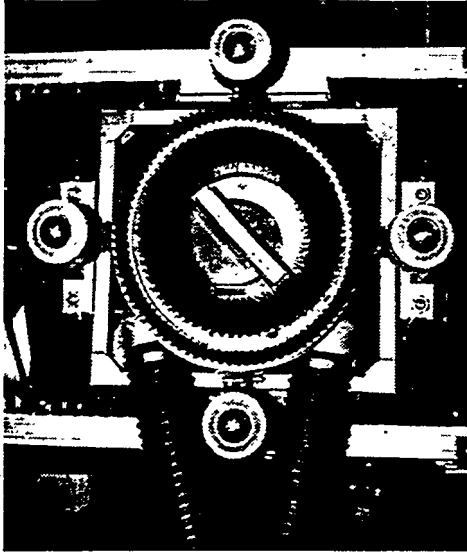


Figure 4 End Effector with Standoff Control Device

Nozzle. The Even-Energy™ nozzle contains more than 20 laser-drilled industrial-sapphires orifices, of varying sizes and placement; the sapphires provide long life, and the size and placement provide even energy distribution. The nozzle body does not wear out from water flow; the orifices in the nozzle body are the only consumables. Nozzle orifices are easily changed-out with a common Allen wrench and the nozzle body is easily removed with adjustable wrenches.

Vacuum Recovery Shroud. A unique vacuum recovery shroud designed to capture virtually 100% of the process water, the suspended paint particles and the fouling residue. The vacuum shroud quickly removes all effluent so as not to diminish the stripping efficiency of the nozzle as it progresses along a hull or other surface. As it removes the process effluent, it simultaneously dries the substrate, leaving a rust-free surface.

Compliance and Standoff Control. A mechanical device is built into the end effector frame to control standoff distance to ensure optimal surface contact and efficient effluent capture over large variations of curved surface contours.

Hydraulic Drive. The transporter's hydraulic power unit rotates the waterjet nozzle. It supplies hydraulic fluid to a motor in the end effector, which drives a high-pressure water swivel through a belt-and-pulley mechanism. Hydraulic power was selected over other chives because of its higher starting torque, accuracy and reliability.

Manipulator Subsystem

The manipulator subsystem (Figure 5) provides the interface between the ship surface and the end effector, which moves back and forth across the manipulator's 1.37- x 1.98-m (4.5- by 6.5-foot) envelope at optimal standoff distance while maintaining contact so the vacuum recovery head can capture all effluents.

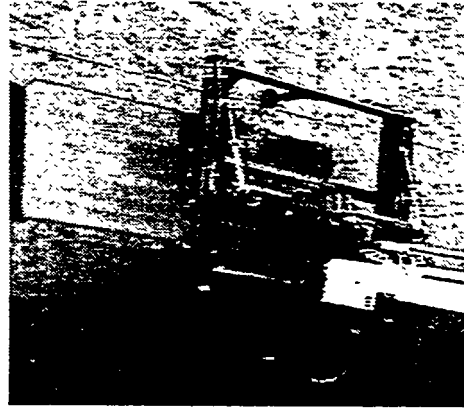


Figure 5 Manipulator and End Effector

Transporter Subsystem

An off-the-shelf, mobile, telescoping transporter subsystem (Figure 6) accurately positions and repositions the manipulator against the ship, barge or other surface to be processed. The transporter is capable of reaching 18.3-m (60-feet) high with 360° continuous rotation. All process hoses and cables are routed along the boom.

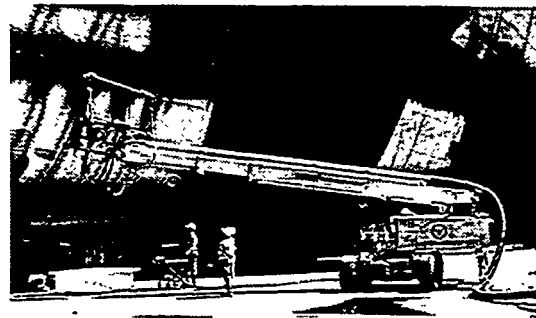


Figure 6 Transporter

Remote Control Console. A console (Figure 7) provides the operator a single point from which to control the transporter, manipulator, high-pressure pump and water reclamation unit. The console is mounted on a roll-around cart so it can be positioned for maximum operator convenience and visibility.

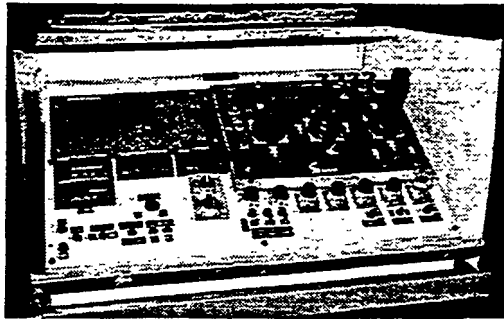


Figure 7 Remote Control Console

Auxiliary Power Generator. A separate power generator is provided on the transporter for operation of the manipulator and the remote control console.

High-Pressure Pump Subsystem

A high-pressure, dual-intensifier, hydraulic water pump (Figure 8) is carried on a separate small trailer. The pump supplies water to the end effector at the required high pressure and volume for the stripping operation.

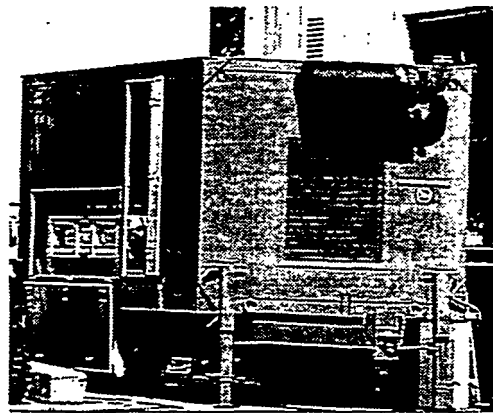


Figure 8 Mobile High-Pressure Water Pump

The pumping unit is self-contained, diesel-powered and ideally suited to the task of stripping thick tough coatings such as anti-foulant topcoat, marine growths, and epoxy primer. It is capable of supplying water to the end effector at up to 37.8 liters per minute (10 gpm) and 2482 bar (36,000 psi). All pressure hoses, tubing and fittings are burst rated at 6207 bar (90,000 psi).

The hydraulic system drives dual, plunger-type intensifiers as part of a closed-loop system. The intensifiers are designed for easy accessibility for maintenance and repair. The hydraulic system includes an integral full-flow filtration system, hydraulic reservoir and pressure gauges.

The operator controls the pump intensifier and pressure from the remote control console, which can be wheeled around the dock for best operator visibility. The pump can also be manually operated at a control panel on the pump face. An automatic protection feature monitors critical pump functions and warns the operator if abnormal parameters are detected.

Effluent-Recovery Subsystem

The process water, paint and fouling residue are collected by the effluent-recovery system for filtering the paint and residue, removing leached ions (copper, cadmium, lead, etc.), microparticulates, chlorides, sulfates, nitrates and other contaminants picked up from the surface. This mobile subsystem is installed in a standard shipping container and chassis (Figure 9).



Figure 9 Pump and Recovery Subsystem Trailer

The effluent first enters the recovery system through a 6-inch vacuum recovery hose attached to the shroud around the nozzle. A dri-prime pump removes the material from the bottom chamber of the vacuum and deposits it into a vibratory **liquid/solid separator**. The separator acts as a "removing about 95% of the solid material". The liquid is then pumped to a micro-separator, which is the first stage of the water reclamation unit. The micro-separator uses centrifugal force to remove all material heavier than water. The water is then passed through a coalescing tank (to remove oils and film), then through an ozone generator, charcoal filter, micro-filters and, finally, a deionization system with conductivity meter to ensure that the water recycled to the pump is Grade A deionized water.

Utility Trailer. To provide system mobility in the limited space of shipyards and dry-docks, the effluent-recovery subsystem is installed in a standard shipping container, which is approximately 12.2-m long x 4.1-m tall x 2.4-m wide (40- x 13.6- x 8-ft). The container can be removed from the chassis and placed flat on the

drydock floor or supported at each corner by a dual-wheeled caster. The container can be moved on these casters with a forklift and towbar.

Vacuum Unit. A high-powered wet/dry vacuum unit (Figure 10) recovers nearly 100% of the process water as the coating is being removed. The liquid/solid slurry is captured in a removable hopper under the vacuum unit in the process trailer. The entrained air is filtered and exhausted to the atmosphere.

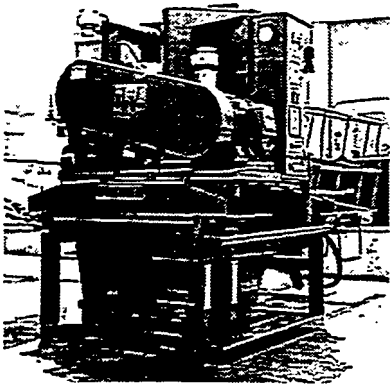


Figure 10 Vacuum Unit

Sump Pump. A dri-prime pump (Figure 11) removes the liquid/solid slurry from the vacuum collection hopper and pumps it to the liquid/solid separator. The pump is capable of handling liquid slurries with solids up to 3.8 cm (1.5 inch) in diameter.

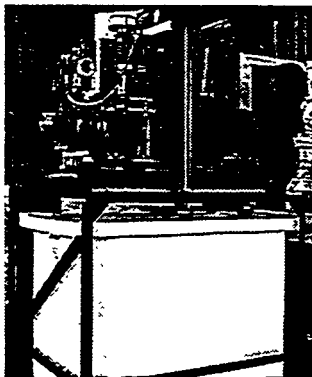


Figure 11 Sump Pump

Liquid/Solid Separator. Because of the large amount of solid waste material generated in stripping a large ship, a customized liquid/solid separator (Figure 12) is used as a preprocessor of the effluent before transfer to the water reclamation unit. An adjustable mesh vibrating screen separates the majority of the solids from the liquid. Those solids are dumped into a 208-liter

(55-gallon) drum for disposal. The remaining dirty water is captured in a collection tank before being pumped to the water reclamation unit for further filtering and water treatment.

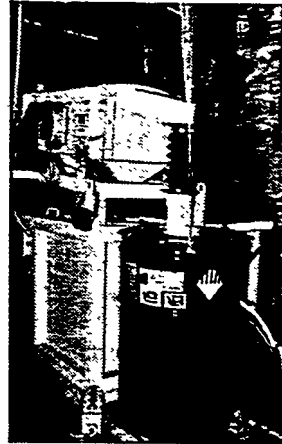


Figure 12 Liquid/Solid Separator

Water Reclamation Unit. A modular water reclamation unit (Figure 13) filters and conditions the used process water and returns it to the high-pressure pump.

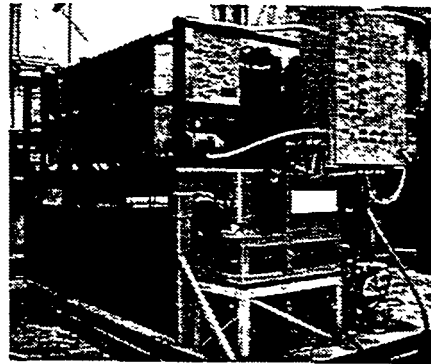


Figure 13 Water Reclamation Unit

The sump pump first directs the water to a centrifugal microseparator, which removes a majority of the particulate. The water from the centrifugal separator is then directed into a 1135-liter (300-gallon) raw water tank. The raw water is pumped through a series of filters, an oil separator, and an ozone generator before being deposited into a 757-liter (200-gallon) clearwell tank. The water in the clearwell tank is then passed through deionization tanks to remove heavy metals, then through a final 0.35 -micron filter for reuse by the system's high-pressure water pump. To compensate for evaporative losses, potable water is automatically added from the system's make-up tank.

Generator. A 125-KW diesel-powered electric generator (Figure 14) powers the vacuum unit, water reclamation unit, air compressor, dri-prime pump, liquid/solid separator and other trailer utilities.

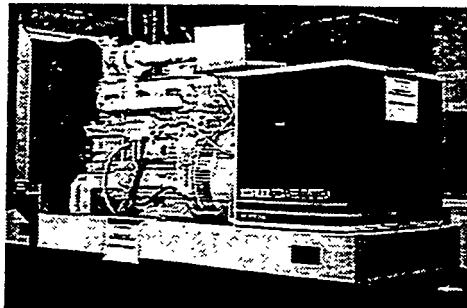


Figure 14 Diesel-Powered Electric Generator

Air Compressor. An electric-driven air compressor (Figure 15) supplies air for operation of the manipulator, pumps, valves and utility equipment.

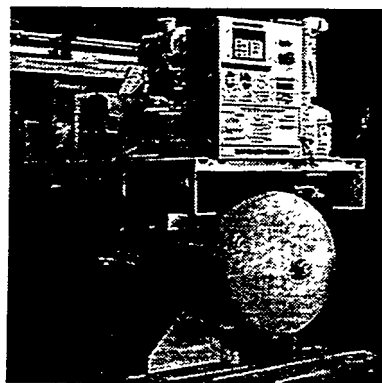


Figure 15 Air Compressor

PANEL TESTS

As part of the Navy Waterjet Demonstration System effort, 40 panels were tested to evaluate paint removal rates, remaining surface contaminants, and paint adhesion after waterjet processing. Specific areas of evaluation include:

- Tooth Profile...to assess waterjet effects and variation in removal rates from varying tooth profile,
- Paint thickness...to evaluate effects of paint thickness on removal rates,
- Removal Quality . . .to assess how various percentages of paint left on the surface after stripping affect paint adhesion, and
- Adverse Effects.. .to determine any adverse effects of waterjet processing from salt-fog and pull-adhesion tests.

SHIPYARD TEST AND DEMONSTRATION

The system was moved to Puget Sound Naval Shipyard on 18 July 1994. Its first test at the yard was the removal of about 46.5 m² (500 ft²) of underwater hull paint from the USS NIMITZ (CVN 68). During test, test, (Figures 16 and 17) the system showed its capability to remove all of the paint to bare metal and selectively strip layers of paint from the surface. The amount of material removed in selective stripping ranged from the first layer of antifoulant to the first layer of anticorrosive. This was performed by varying the water pressure and nozzle speed across the ship's hull.

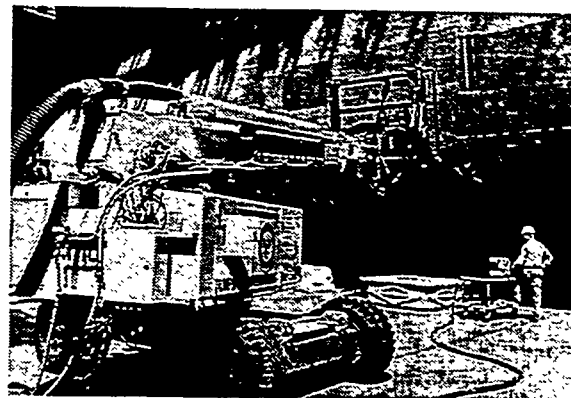


Figure 16 Stripping USS NIMITZ



Figure 17 Manipulator on NIMITZ Hull

The coating system on the NIMITZ underwater hull consisted of two coats of International FP Series anticorrosive paint and four coats of BRA Series antifoulant paint. The coating had been on for less than 4 years, averaged 30-40 mils thick and was in excellent shape. The ship was sent back out with the paint system intact except in the areas where the tests were performed and anew coating was applied.

The removal rate achieved was 12.6 m²/hour (136 ft²/hour). This is only the time required to remove the paint from the 1.37- x 1.98-m (4.5-by 6.5-foot) work envelope, not the time to move the manipulator frame from spot to spot, which takes only a few minutes.

The vacuum recovery shroud on the system performed well; after some minor adjustments were made, it achieved 100% effluent recovery. After the paint was removed, the bare metal did not flash rust. This is because of the strong vacuum and the -60 C (-140 F) heat of the water, which speeds evaporation and eliminates the potential for surface flash rusting.

The water and effluent were tested for trace metals as it entered and left the effluent recovery system. The measured values are listed in Table I.

<u>Metal</u>	<u>Effluent Recvcd</u>	
	<u>(mg/L)</u>	<u>Water (mg/L)</u>
Zinc	13.2	<0.10
Lead	<0.10	<0.10
Barium	17.3	0.14
Arsenic	0.10	<0.10
Selenium	0.20	<0.10
Copper	19.7	0.11
Silver	<0.10	<0.10
Cadmium	<0.10	<0.10
Nickel	0.39	<0.10
Chromium	0.39	<0.10

Table I Analysis of Effluent

Most of the paint residue is pulled out by the liquid/solid separator and deposited into a 208-liter (55-gallon) drum (Figure 18). This waste was also analyzed, and results are listed in Table II.



Figure 18 Solid Waste Collected

<u>Metal</u>	<u>Qty</u> <u>(mg/kg)</u>
Zinc	2700
Lead	217
Barium	1950
Arsenic	<20
Selenium	<20
Copper	296,000
Silver	<20
Cadmium	<20
Nickel	329
chromium	234

*Method: EPA 3050A & 6010A

Analysis Dates: 26&29 Sep 94

Table II Analysis of Solid Waste

The next test was removal of non-skid coating from the flight deck of the NIMITZ (Figures 19 and 20). Data was not collected on the coating thickness, but the entire coating system was removed at a rate of 19 m²/hour (205 ft²/hour).

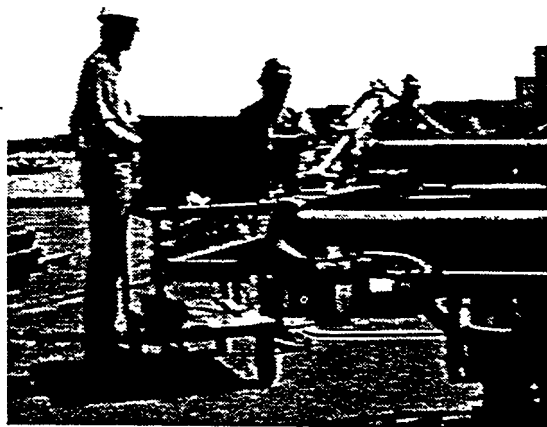


Figure 19 Setting Up for Deck Stripping

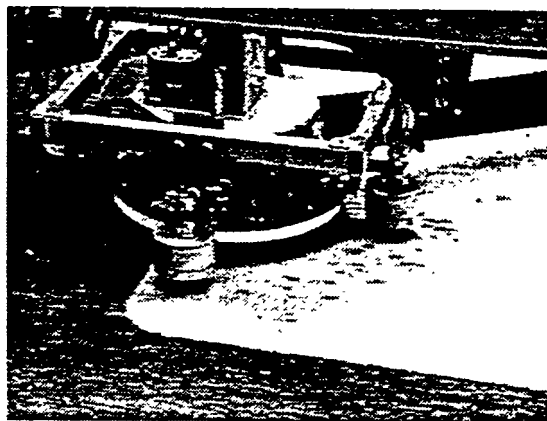


Figure 20 Stripping Non-Skid Deck Surface

The system was then moved to Drydock 1 at Puget Sound to begin testing on the USS STURGEON (SSN 637). Several thousand square meters (feet) were stripped, demonstrating both selective stripping and complete stripping to bare metal.

It appears that the STURGEON had a 4 or 5 coat system, but both the number of coats and the total thickness varied due to many touchups. The paint system was in fair condition and came off faster than in the NIMITZ testing a removal rate **of about 16.7 m²/hour (180 ft²/hour) was achieved** on the STURGEON (Figures 21 and 22).

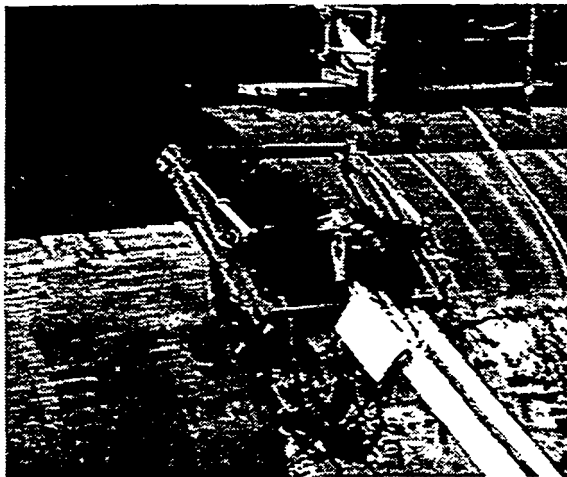


Figure 21 Stripping the USS STURGEON

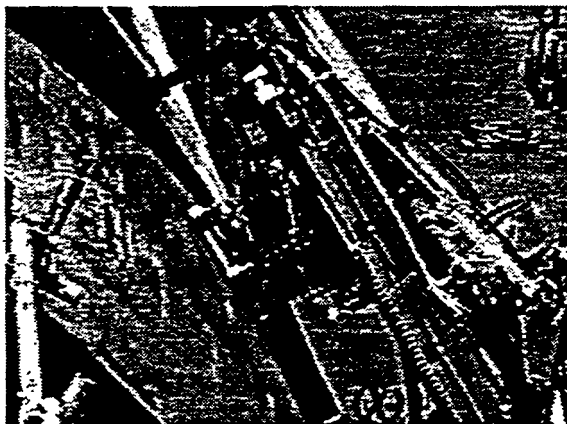


Figure 22 Side View of STURGEON

The surface was tested after paint removal to quantify the amount of chlorides remaining on the substrate. The Bressle Method Test Kit and Swab Kit were used and, in all tests, the readings were **from 0 to 2 µg/cm². The vacuum recovery head** performed well, and areas that were stripped to bare metal did not rust for 9 days, until a rainstorm

washed the salts down from the unstripped areas above.

On 20 October, the system was shipped to Pearl Harbor Naval Shipyard (PHNSY) to remove **2322.5 m² (25,000 ft²) of freeboard paint from the** USS Leftwich (DD 984). Since the Leftwich had organotin on the underwater hull, dry abrasive blasting or open water blasting was not permitted on the freeboard until all the organotin was removed and the drydock was thoroughly cleaned. This sequential process would lengthen the LEFTWICH's time in drydock, so PHNSY requested the use of the Navy Waterjet Demonstration System to see if it could remove both coatings simultaneously and reduce the ship's time in drydock.

The freeboard of the LEFTWICH had a 2-year-old coating system in excellent condition, consisting of 5-coats: one coat of Cathacote 302 Zinc-Rich Epoxy, one coat of MIL-P-24441 Formula 154 Epoxy, and three coats of TT-P-490 Haze-Gray Enamel.

This was the first "production" test of the Waterjet Demonstration System, and it performed well, removing the 5-coat system at a rate of **19 m²/hour (205 ft²/hour).**

The Leftwich work provided the project team with valuable information that is being incorporated into the second-generation, production version of the system. The work at PHNSY will continue through January 1995. The equipment will then be moved to Long Beach Naval Shipyard for further prototype testing on the USS FOSTER (DD 964).

CONCLUSION

The prototype system is performing better than expected for a technology-demonstration unit. Design work is already proceeding on a production version of the mobile waterjet stripping system.

Ongoing work with the prototype and production systems will be closely monitored and detailed information will be collected on mean time between failure (MTBF), operating costs, cost savings, maintenance schedules, surface conditions, production removal rates, paint adhesion, and overall success of the system.

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